B. Laser Glazing of Railroad Rails to Reduce Friction

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Objective

- Determine the potential of laser glazing to lower parasitic energy losses between the flange and the rail in rail transport.
- Develop a fundamental understanding of the metallurgy associated with the formation of low-friction surface layers during laser glazing processing and how these layers reduce friction between rail and wheel

Approach

- Develop advanced laser glazing processes to form glazed regions on carbon steels.
- Perform benchtop tests, full-scale rig tests, and field tests of glazed steels and rails to quantify the impact of glazing on parasitic friction losses.
- Characterize glazed and nonglazed steels to elucidate the impact of glazing on the microstructure.

Accomplishments

- Optimized laser processing conditions under which uniform glazed surfaces form on carbon steels.
- Evaluated the friction and wear performance of glazed (and unglazed) rail steel by using benchtop and wheel/rail rig tests.
- Characterized the microstructure and hardness of glazed steels.
- Developed a deformation theory for nanocrystalline materials to model friction in glazed steel.
- Demonstrated the efficacy of laser glazing to reduce friction on a full-scale test rig using prototype wheels, loads, and speeds.

Future Direction

- Perform high-tonnage field tests at the Association of American Railroads (AAR)/Transportation Technology Center, Inc. (TTCI) Facility for Accelerated Serving Testing (FAST) in Pueblo, CO.
- Characterize the microstructure of a glazed rail subjected to AAR/TTCI FAST tests.

- Make go/no-go decision to proceed with development of rail glazing technology.
- If go/no-go decision is to proceed, establish project with a railroad track maintenance equipment and service organization

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Introduction

Wheel/rail interaction accounts for a significant fraction of the energy consumed in rail transport. Past studies have indicated that energy savings could be as high as 24% when friction at the wheel/rail interface is properly managed. The key aspect is control of the friction forces. At the locomotive, high friction between the rail (specifically the top of the rail) and the wheel is desired to ensure adequate traction to keep wheels from slipping and sliding when power is applied. Friction is also required under braking conditions to control the speed of downhill-bound trains or to bring a train to a safe stop. The trailing cars, however, require much lower friction levels under normal train operations. At these cars, a low, controllable friction is desirable and can significantly reduce the energy required to pull a train. Two regions account for most of the frictional losses between the wheel and the rail: the region between the top of the rail and the wheel tread, and the region between the wheel flange and the gage face of the rail. Current wheel/rail lubrication (e.g., application of degradable greases and lubricants) is inconsistently applied and often disengaged by train crews. The research described herein focuses on the development of a laser glazing technique that imparts a durable, low-friction surface to the gage face of the rails to reduce parasitic frictional losses between the flange and rail gage.

Approach

The objective of this activity was to develop an advanced laser modification process to form a glaze on the gage face of the rail. Initial results and models predicted the formation of a nanocrystalline surface layer that would impart low-friction properties at the interface. The tasks associated with this project involve

- Process development (laser glazing)
- Microstructural characterization of laser-modified surfaces
- Development of a model (of surface deformation)
- Lab-scale friction and wear testing of laser-modified surfaces (glazed and shot-peened)
- Full-scale friction testing of laser-glazed steel

Results

The development of the laser glazing processes used in these studies[1,2] was documented in the FY 2003 Annual Report. Several approaches were investigated; two involved laser glazing, and a third investigated a laser shock-peening technique. Parametric studies were performed to optimize the conditions under which a glazed layer forms on 1080 steel. For this purpose, an Electrox 1.6-kW pulsed Nd:YAG laser with fiber-optic beam delivery and special beam shaping optics was used in Argonne National Laboratory's (ANL's) Laser Applications Laboratory. Two approaches were developed: one involved a single pass of the laser over a given area, and the other involved multiple overlapping passes. The Knoop hardness of the martensitic glazed regions was 2–3 times greater than that of the substrate, depending on whether a single-pass (factor of 3 times harder) or multipass (slightly over 2 times harder) process was employed. A commercial laser glazing process that used high-power diode laser technology was also investigated. In this case, bars of 1080 steel were processed by a commercial vendor (NuVonyx) and subsequently tested at ANL.

Friction and wear studies were performed using a number of lab-scale systems. Block-on-ring tests performed by Falex Corp. showed static friction coefficients of ≈0.35–0.45 for untreated 1080 steel that dropped to values ranging from 0.2 to 0.4 for differing glazing conditions. Large-scale (using a glazed segment of rail and a full-size wheel) "block-on-ring" tests performed at the AAR/TTCI Pueblo facility showed the static friction coefficient of the untreated 1080 rail varied from 0.2 to 0.5, depending on the applied load, whereas the friction coefficient of the glazed regions varied from 0.1 to 0.25. Dynamic friction coefficients for the glazed regions varied from 0.2 to 0.35, depending on load, compared with 0.2 to 0.55 for unglazed regions.

Benchtop pin-on-disc tests at ANL used flats of 1080 steel, glazed and unglazed, that rubbed against stationary balls or pins (52100 steel, 1080 steel, 440C steel, or alumina). The tests revealed that the composition of the pin/ball had a significant impact on the friction coefficient. The general trend was that the glazing reduced the friction coefficient by 3–35%, depending on the material. The greatest reduction was for the alumina ball sliding against the 1080 steel, suggesting that a strong chemical adhesion mechanism may be active with the metallic counterparts.

Twin roller tests were conducted at ANL with 1045 steel rail and wheel discs that were through-hardened (Rc 40) or glazed. The glazing effectively reduced the friction coefficient from roughly 0.4 for the unglazed condition to 0.3 for the glazed rail rotating against an unglazed 1045 steel counterpart.

The most recent set of tests was performed in a twin-roller test rig at the Canadian National Research Center (CNRC) Wheel, Bearing, and Brake (WBB) facility in Ottawa, Ontario (Figure 1). The WBB Facility uses conventional and instrumented full-scale wheelsets loaded against large 63-in.-diam rims that simulate the track. The system is designed to operate at prototypical speeds and loads (30 mph and 33,000 lb in these tests). The instrumented wheelset allowed continuous monitoring of the lateral, longitudinal, and vertical forces during the tests—a feature that was used to measure differences between glazed and nonglazed regions on rim A in Figure 1.

The WBB tests were performed to confirm the friction reductions observed in the lab-scale tests and to evaluate the durability of the glazed regions before glazed rail segments were installed in the FAST loop at the AAR/TTCI facilities. A 180° segment of rim A was sent to NuVonyx, where two 10–12-mm-wide tracks were glazed along the circumference of the rim—one track along the gage face and the second track on the top of the rail approximately 5 mm from the gage point.

A series of runs was performed over a 5-day period to evaluate the efficacy of the glazing to reduce lateral and longitudinal forces (e.g., reduce friction) and to evaluate the durability of the glazing after

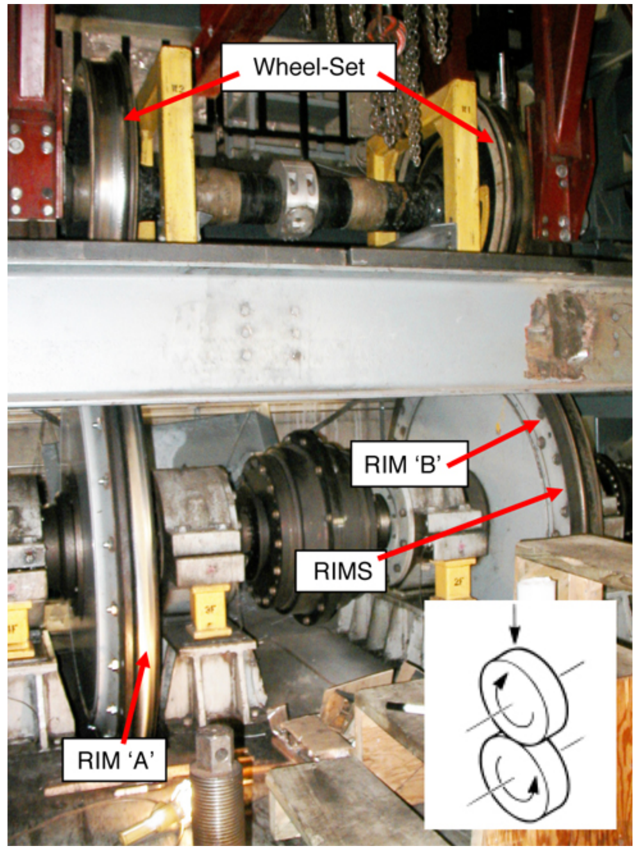

Figure 1. CNRC Wheel, Bearing, and Brake Test Facility.

moderate tonnage. The friction measurements were performed with an instrumented wheelset that permitted direct measurement of the forces using strain gauges applied to the rotating wheels. These provided a continuous measurement of the lateral, longitudinal, and vertical forces. Figure 2 shows an example of the vertical load and friction coefficient measured during a lightly loaded (10,000 lb), low-speed (6 mph) run at the start of the tests.

Because the laser-glazed rim was not re-profiled before the start of the CNRC tests, the vertical loading trace (see Figure 2) provided an easy method to determine when the wheelsets were running against the 180° glazed segment or the non-glazed segment. As seen in Figure 2, the friction shows a cyclic period of approximately 2 seconds, corresponding to one revolution of the bottom rims (at 6 mph). When the wheelset is running on the smooth, nonglazed 180° segment, the friction coefficient is high (approximately 0.18 in Figure 2). When the wheelset runs on the glazed segment, the friction drops to approximately 0.16—a decrease of 10 to 11%.

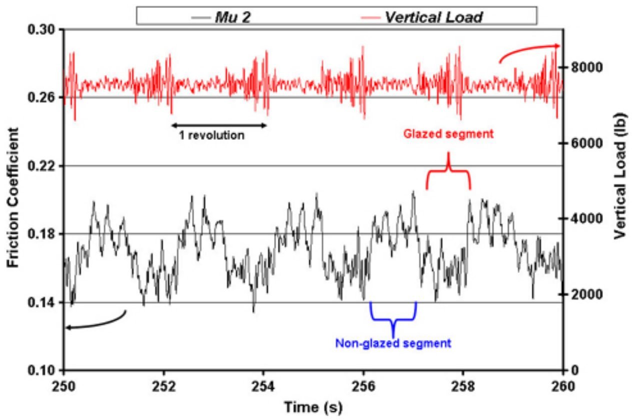

Figure 2. Friction and WBB vertical load between 250 and 260 seconds during run 1b of the ANL/CNRC rail glazing tests.

The data shown in Figure 2 present a snapshot in time during this particular run, during which the top wheelset was gradually yawed with respect to the bottom rims—a process that simulates a train passing through a curve, or the wheels hunting back-and-forth down a straight tangent run. Figure 3 summarizes the impact of the glazing observed during the entire duration of this particular run (run 1b). The magnitude of the friction reduction depends on a number of factors, including the yaw angle. As the yaw increases, the magnitude of the lateral and longitudinal forces increases and thus the friction coefficient increases, from values near 0.1 at low yaw to 0.4 to 0.5 at high yaw. The impact of the glazing on reducing the friction was not as significant at higher yaw, where the lateral forces dominated the friction measurements. Overall, Figure 3 shows that the glazing treatment reduced the friction coefficient by 8 to 50% depending on the yaw—with the greater friction reductions occurring at low yaw.

After the initial series of friction tests, a conventional wheelset was installed and a series of long-duration runs was initiated at high yaw and side loadings to expose the glazed regions to high tonnage to determine if the glazing was durable. Approximately 1 MGT (million gross tons) was applied to the glazed regions. The instrumented wheelset was then reinstalled and another series of friction measurements performed.

The magnitude of the friction reduction decreased from values observed during the initial measurements (run 1b); nevertheless, friction reduce

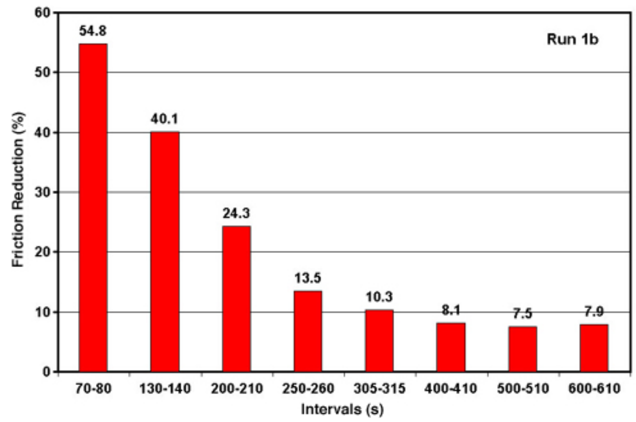

Figure 3. Friction reduction on glazed rim (normalized to the unglazed rim segment) for run 1b.

tions in the range of 8 to 40% were consistently observed.

Figure 4 shows a photograph of the bottom rim after the high-tonnage runs. These runs consisted of 2–3 days of operation at high loads (33,000 lb), high speed (30 mph), and high yaw that accumulated roughly 6 hours of run time. White paint, applied early during the runs to adjust the position of the top wheelset to ensure it was running on the glazed tracks, indicated the glazed track on the top of the rail was in contact with the wheelset. Magnaflux characterization of the rim further indicated the

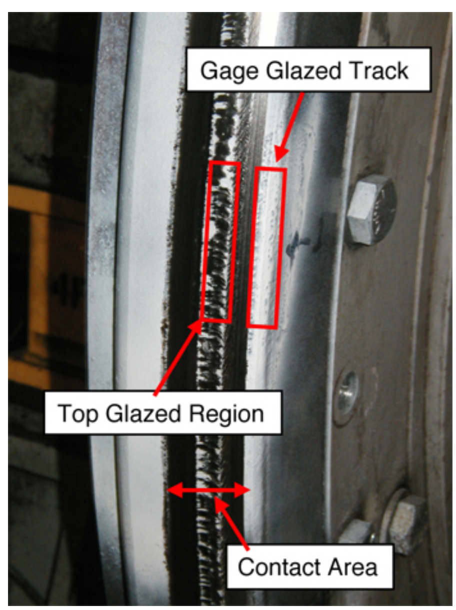

Figure 4. Macrophoto of glazed rim after run 4d.

glazed track remained intact over most of the 180° segment, although a short segment of glazed material (approximately 3 mm wide by 5 cm long) was removed after the severe high-load, high-yaw runs. The loss of the glazed material was aggravated because the glazed tracks were tested in the "as-glazed state" (a condition in which the glazed region was significantly rougher than a conventional rail profile), resulting in high contact stresses. Re-profiling the as-glazed track will reduce the high contact stresses and thus should mitigate fatigue-induced pullout/loss of glazed material.

Conclusions

Testing of laser glazing to improve the friction (and wear) performance of steels continues to progress. Initial lab-scale tests showed significant friction reductions, and the more recent studies at CNRC Ottawa have confirmed the friction reductions using full-scale wheels under high loads and prototypical speeds. Friction reductions in the range of 10 to 40% have been observed—the magnitude of the reduction being dependent on the yaw and side loading.

Efforts are in progress to establish a team to commercialize this technology with a rail maintenance firm. Plans are being developed to glaze a series of 20- to 40-foot-long track segments that will be installed in the FAST loop at the AAR/TTCI facility in Pueblo. The FAST loop tests will involve track segments in the as-glazed, and as-glazed and re-profiled state. The FAST loop tests are designed to put significant levels of tonnage on the treated track (upward of 100 MGT). If they are successful, arrangements are being made to incorporate a laser-glazing system on a rail maintenance vehicle.

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